CHARLES DARWIN UNIVERSITY

Family Name	
Given Names	
Student Number	
Teaching Period	Semester 1, 2017

FINAL EXAMINATION	DURATION
ENG487 – HVAC Systems	Reading Time: **10** minutes Writing Time: **180** minutes

INSTRUCTIONS TO CANDIDATES

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 16 Page Book 1 x Scrap Paper

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Question 1 *(25 marks)*

A space heating system is being designed with a total space heating load of 500,000 Btu/hr (145kW). The space must be maintained at 70F (21C) dry bulb (db) and 30% relative humidity (RH). Outdoor air enters the preheat coil at 35F and essentially 0% RH, where it is heated to 60F (16C) and then mixed with return air. The mixture is first heated and then humidified, in a separate process, to 105F (40C) and 30% RH for use as supply air to the space. Saturated steam at ***2 psig*** is used for humidification. 25% (by mass) of the supply air is outdoor air.

a) *Draw the block diagram for the system and sketch the psychrometric processes. (Use plain charts provided on pages 4 and 5).*
b) *Calculate the volume flow rate of supply air.*
c) *Calculate the heat transfer rates in both preheating and heating coils.*
d) *Calculate the steam flow rate.*
e) *What is the sensible heat factor (SHF) for the heating system?*

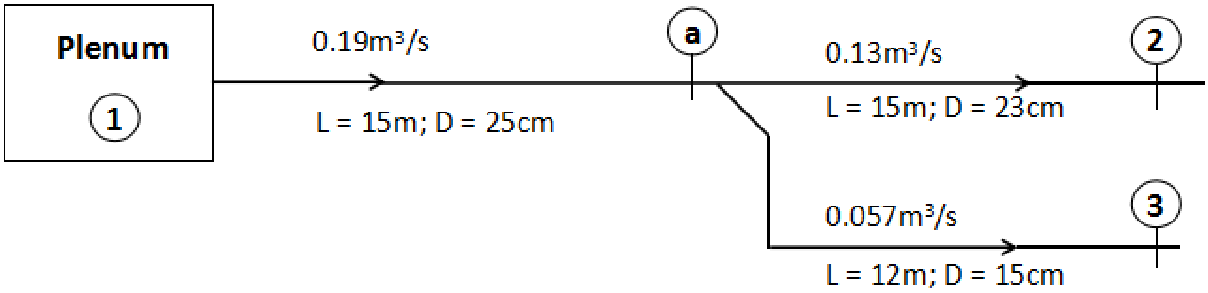
Question 2 *(25 marks)*

A lecture theater with a capacity of 225 students must be conditioned at 75F (24C) db and 50% RH. The cooling load is 125,000 Btu/hr (37kW) with a SHF of 0.7. The minimum supply air of 15cfm/student (7.5L/s per student) is assumed adequate.

Determine the volume flow rate and conditions of the supply air. (You may use plain charts provided on pages 4 and 5).

Question 3 *(25 marks)*

A simple duct system is given below:

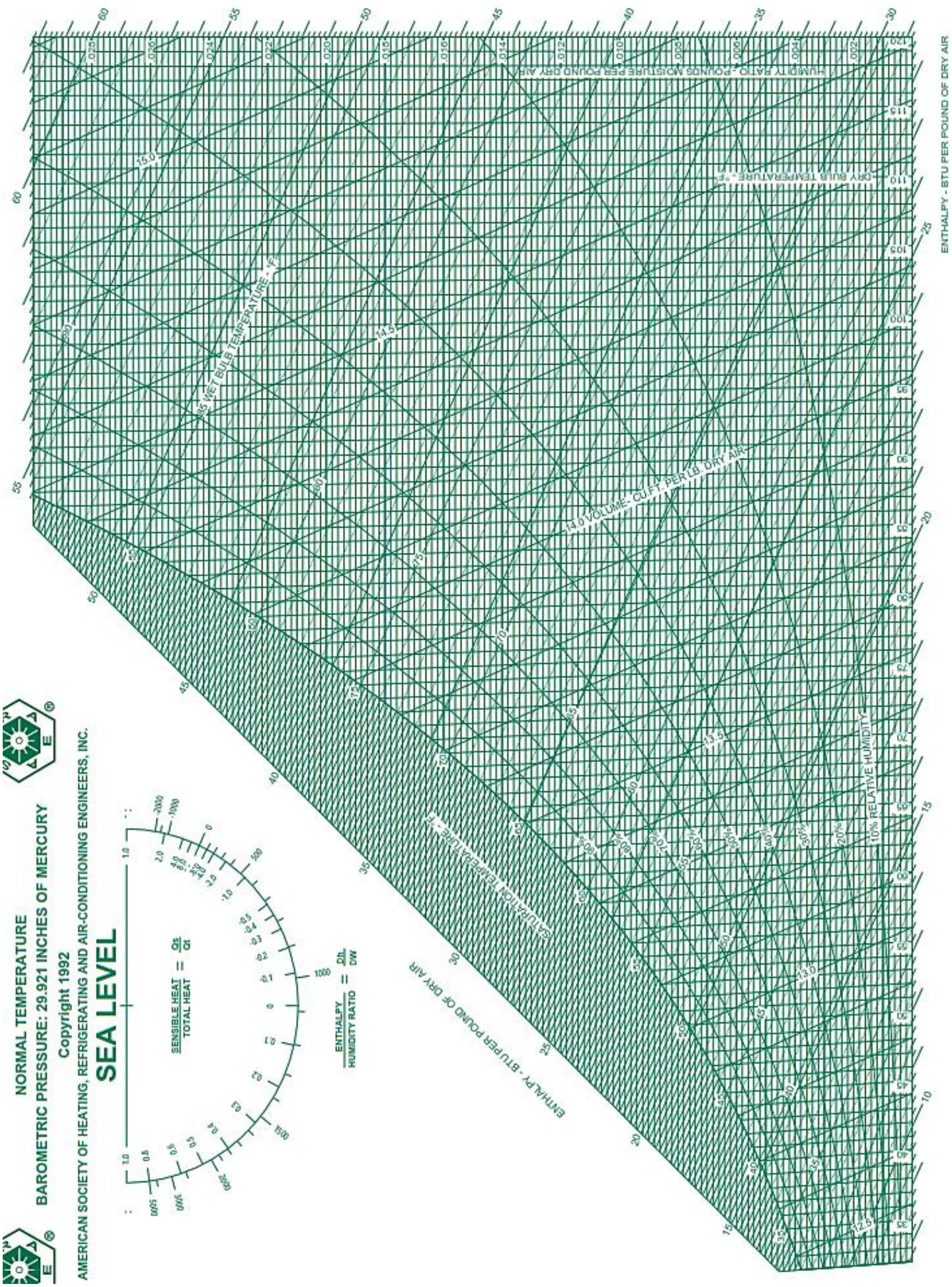


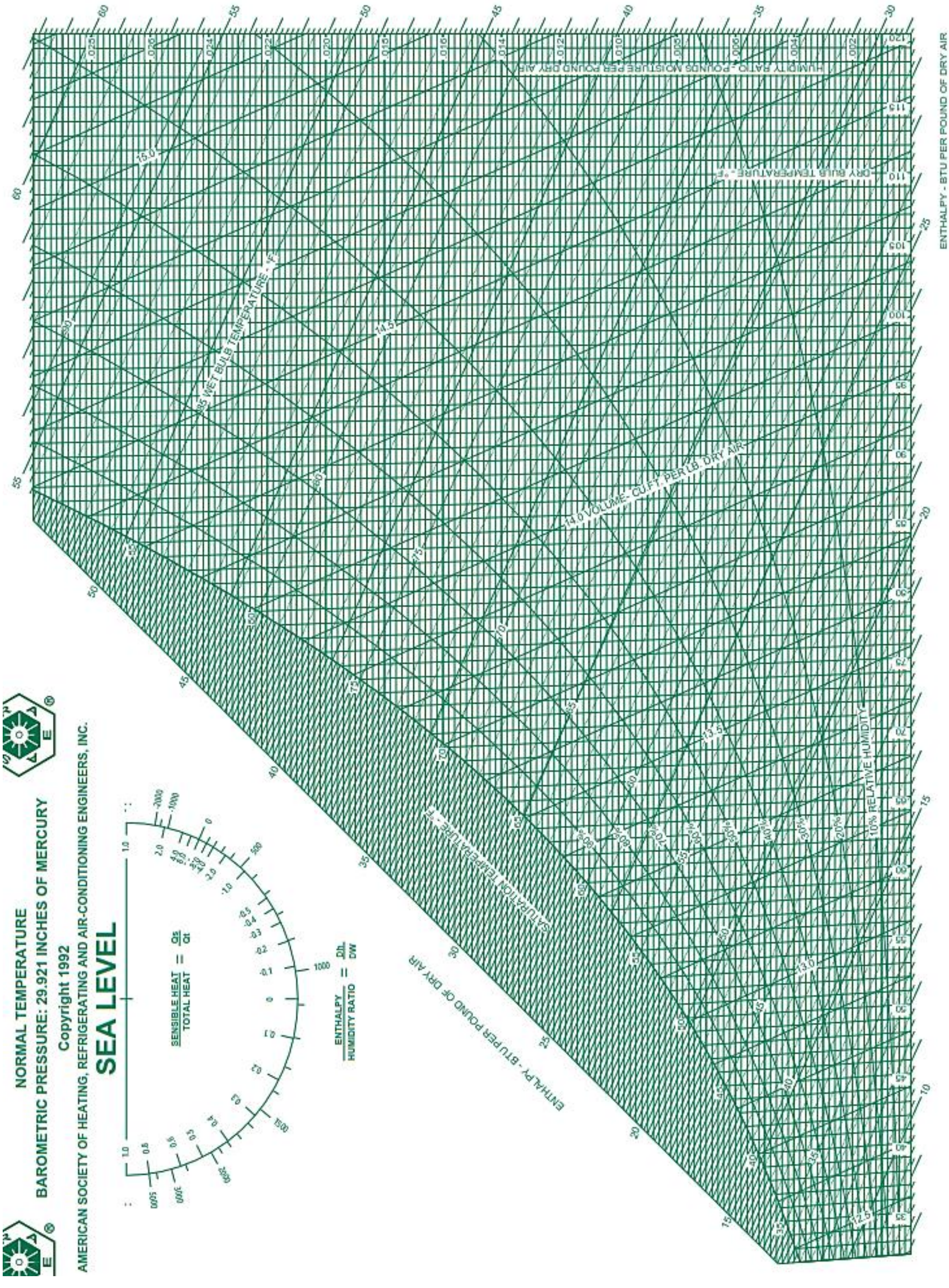
Calculate the lost pressure for each branch in this system. (State all assumptions).

Question 4 *(25 marks)*

In designing a house, the total heat loss is calculated as 17.9 kW. The heat loss through the outside walls is 28% of the total heat loss, and the overall coefficient for the outside walls is 1.4 W/(m^2·K).

If a 50 mm thick layer of organic bonded fiberglass is used to insulate the wall, determine the new total heat loss for the house.


NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 29.921 INCHES OF MERCURY
Copyright 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SEA LEVEL
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
VOLUME- CU.FT. PER LB. DRY AIR
RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR



NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 29.921 INCHES OF MERCURY
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VOLUME- CU.FT. PER LB. DRY AIR
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
10% RELATIVE HUMIDITY

<u>**Resources**</u>

Tables and Diagrams

TABLE A–4E

Saturated water—Temperature table

		Specific volume, ft^3/lbm		*Internal energy,* Btu/lbm			*Enthalpy,* Btu/lbm		
Temp., T °F	Sat. press., P_{sat} psia	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g
32.018	0.08871	0.01602	3299.9	0.000	1021.0	1021.0	0.000	1075.2	1075.2
35	0.09998	0.01602	2945.7	3.004	1019.0	1022.0	3.004	1073.5	1076.5
40	0.12173	0.01602	2443.6	8.032	1015.6	1023.7	8.032	1070.7	1078.7
45	0.14756	0.01602	2035.8	13.05	1012.2	1025.3	13.05	1067.8	1080.9
50	0.17812	0.01602	1703.1	18.07	1008.9	1026.9	18.07	1065.0	1083.1
55	0.21413	0.01603	1430.4	23.07	1005.5	1028.6	23.07	1062.2	1085.3
60	0.25638	0.01604	1206.1	28.08	1002.1	1030.2	28.08	1059.4	1087.4
65	0.30578	0.01604	1020.8	33.08	998.76	1031.8	33.08	1056.5	1089.6
70	0.36334	0.01605	867.18	38.08	995.39	1033.5	38.08	1053.7	1091.8
75	0.43016	0.01606	739.27	43.07	992.02	1035.1	43.07	1050.9	1093.9
80	0.50745	0.01607	632.41	48.06	988.65	1036.7	48.07	1048.0	1096.1
85	0.59659	0.01609	542.80	53.06	985.28	1038.3	53.06	1045.2	1098.3
90	0.69904	0.01610	467.40	58.05	981.90	1040.0	58.05	1042.4	1100.4
95	0.81643	0.01612	403.74	63.04	978.52	1041.6	63.04	1039.5	1102.6
100	0.95052	0.01613	349.83	68.03	975.14	1043.2	68.03	1036.7	1104.7
110	1.2767	0.01617	264.96	78.01	968.36	1046.4	78.02	1031.0	1109.0
120	1.6951	0.01620	202.94	88.00	961.56	1049.6	88.00	1025.2	1113.2
130	2.2260	0.01625	157.09	97.99	954.73	1052.7	97.99	1019.4	1117.4
140	2.8931	0.01629	122.81	107.98	947.87	1055.9	107.99	1013.6	1121.6
150	3.7234	0.01634	96.929	117.98	940.98	1059.0	117.99	1007.8	1125.7
160	4.7474	0.01639	77.185	127.98	934.05	1062.0	128.00	1001.8	1129.8
170	5.9999	0.01645	61.982	138.00	927.08	1065.1	138.02	995.88	1133.9
180	7.5197	0.01651	50.172	148.02	920.06	1068.1	148.04	989.85	1137.9
190	9.3497	0.01657	40.920	158.05	912.99	1071.0	158.08	983.76	1141.8
200	11.538	0.01663	33.613	168.10	905.87	1074.0	168.13	977.60	1145.7
210	14.136	0.01670	27.798	178.15	898.68	1076.8	178.20	971.35	1149.5
212	14.709	0.01671	26.782	180.16	897.24	1077.4	180.21	970.09	1150.3
220	17.201	0.01677	23.136	188.22	891.43	1079.6	188.28	965.02	1153.3
230	20.795	0.01684	19.374	198.31	884.10	1082.4	198.37	958.59	1157.0
240	24.985	0.01692	16.316	208.41	876.70	1085.1	208.49	952.06	1160.5

Source: Y. A. Cengel, M. A. Boles, Thermodynamics: An Engineering Approach, 5th Edition

Table 5-1a Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a] *(continued)*

Description	Thickness, in.	Density ρ, lbm/ft³	Conductivity k, (Btu-in.)/(hr-ft²-F)	Conductance C, Btu/(hr-ft²-F)	Specific Heat, Btu/(lbm-F)
Board and Slabs					
Cellular glass	—	8.0	0.33	—	0.18
Glass fiber, organic bonded	—	4.0–9.0	0.25	—	0.23
Expanded polystyrene, molded beads.	—	1.0	0.36	—	—
Mineral fiber with resin binder	—	15.0	0.29	—	0.17
Core or roof insulation	—	16–17	0.34	—	—
Acoustical tile	0.50	—	—	0.80	0.31
Acoustical tile	0.75	—	—	0.53	—
Loose Fill					
Cellulosic insulation (milled paper or wood pulp)	—	2.3–32	0.27–0.32	—	0.33
Perlite, expanded	—	2.0–4.1	0.27–0.31	—	0.26
	—	4.1–7.4	0.31–0.36	—	—
	—	7.4–11.0	0.36–0.42	—	—
Mineral fiber (rock, slag, or glass)					
approx. 3.75–5 in.	—	0.6–2.0	—	0.091	0.17
approx. 6.5–8.75 in.	—	0.6–2.0	—	0.053	—
approx. 7.5–10 in.	—	0.6–2.0	—	0.045	—
approx. 10.25–13.75 in.	—	0.6–2.0	—	0.033	—
Mineral fiber (rock, slag, or glass) approx. 3.5 in. (closed sidewall application)	—	2.0–3.5	—	0.077	—
Vermiculite, exfoliated	—	7.0–8.2	0.47	—	0.32
	—	4.0–6.0	0.44	—	—

Source: F. C. McQuiston, J. D. Parker, J. D. Spitler, Heating, Ventilating and Air Conditioning: Analysis and Design, 6th Edition

To Convert From:	To:	Multiply By:
lb_f/in^2 (psi)	pascal (Pa)	6894.757
pascal (Pa)	lb_f/in^2 (psi)	1.4504E-4
g/cm^3	lb/ft^3	62.427974
lb/ft^3	kg/m^3	16.01846
lb/in^3	kg/m^3	27,679.90
lb/ft^3	g/cm^3	0.01601846
volts/mil	kV/mm	0.039370
mil (0.001 inch)	cm	2.54E-3
cm	mil	393.70
$MPa(m^{1/2})$	$psi(in^{1/2})$	910.06
J/(g-°C)	BTU/(lb-°F)	0.239006
BTU/(lb-°F)	J/(g-°C)	4.184000
joule (J)	cal (thermochemical)	0.2390057
cal (thermochemical)	joule (J)	4.184000
joule (J)	BTU (thermochemical)	9.4845E-4
BTU (thermochemical)	joule	1054.350
µm/(m-°C)	µin/(in-°F)	0.55556
µin/(in-°F)	µm/(m-°C)	1.80
cm^3/Kg	in^3/lb	0.027680
in^3/lb	cm^3/kg	36.127
W/(m K)	BTU in /(hr ft^2 F)	6.9334713
BTU in /(hr ft^2 F)	W/(m K)	0.1441314
(J m)/(min m^2 C)	W/(m-K)	0.016667
W/(m-K)	(J m)/(min m^2 C)	60

Source: http://www.matweb.com/tools/unitconverter.aspx

Table 12-14 Approximate Equivalent Lengths for Selected Fittings in Circular Ducts[a]

Fitting	L/D	Equivalent Length, ft (m) at Diameter, in. (cm) 6 (15)	8 (20)	10 (25)	12 (30)
Elbows					
Pleated, 90 deg	15	8 (2.4)	10 (3.1)	13 (4.0)	15 (4.6)
Pleated, 45 deg	9	5 (1.5)	6 (1.8)	8 (2.4)	9 (2.7)
Mitered, 90 deg	60	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)
Mitered with vanes	10	5 (1.5)	7 (2.1)	8 (2.4)	10 (3.1)
Transitions					
Converging, 20 deg	4	2 (0.6)	3 (0.9)	3 (0.9)	4 (1.2)
Diverging, 120 deg	40	20 (6.1)	27 (8.2)	33 (10.1)	40 (12.2)
Abrupt expansion	60	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)
Round to rectangular boot, 90 deg	50	25 (7.6)	33 (10.1)	40 (12.2)	50 (15.2)
Round to rectangular boot, straight	10	5 (1.5)	7 (2.1)	8 (2.4)	10 (3.1)
Entrances					
Abrupt, 90 deg	30	15 (4.6)	20 (6.1)	25 (7.6)	30 (9.1)
Bellmouth	12	6 (1.8)	8 (2.4)	10 (3.1)	12 (3.7)
Branch Fittings, Diverging					
Wye, 45 deg, branch	20	10 (3.1)	13 (4.0)	17 (5.2)	20 (6.1)
Wye, 45 deg, through	8	4 (1.2)	5 (1.5)	7 (2.1)	8 (2.4)
Tee, branch	40	20 (6.1)	27 (8.2)	33 (10.1)	40 (12.2)
Tee, through	8	4 (1.2)	5 (1.5)	7 (2.1)	8 (2.4)
Branch Fittings, Converging[b]					
Wye, 45 deg, branch	20	10 (3.1)	13 (4.0)	17 (5.2)	20 (6.1)
Wye, 45 deg, through	10	5 (1.5)	7 (2.1)	8 (2.4)	10 (3.1)
Tee, branch	40	20 (6.1)	27 (8.2)	33 (10.1)	40 (12.2)
Tee, through	12	6 (1.8)	8 (2.4)	10 (3.1)	12 (3.7)

[a]Equivalent lengths are approximate and based on Tables 12-7 through 12-12 using typical operating conditions with velocity less than about 1200 ft/min or 6 m/s.
[b]It is difficult to assign one value of L/D to this type fitting. Consult Table 12-12.

Source: F. C. McQuiston, J. D. Parker, J. D. Spitler, Heating, Ventilating and Air Conditioning: Analysis and Design, 6th Edition

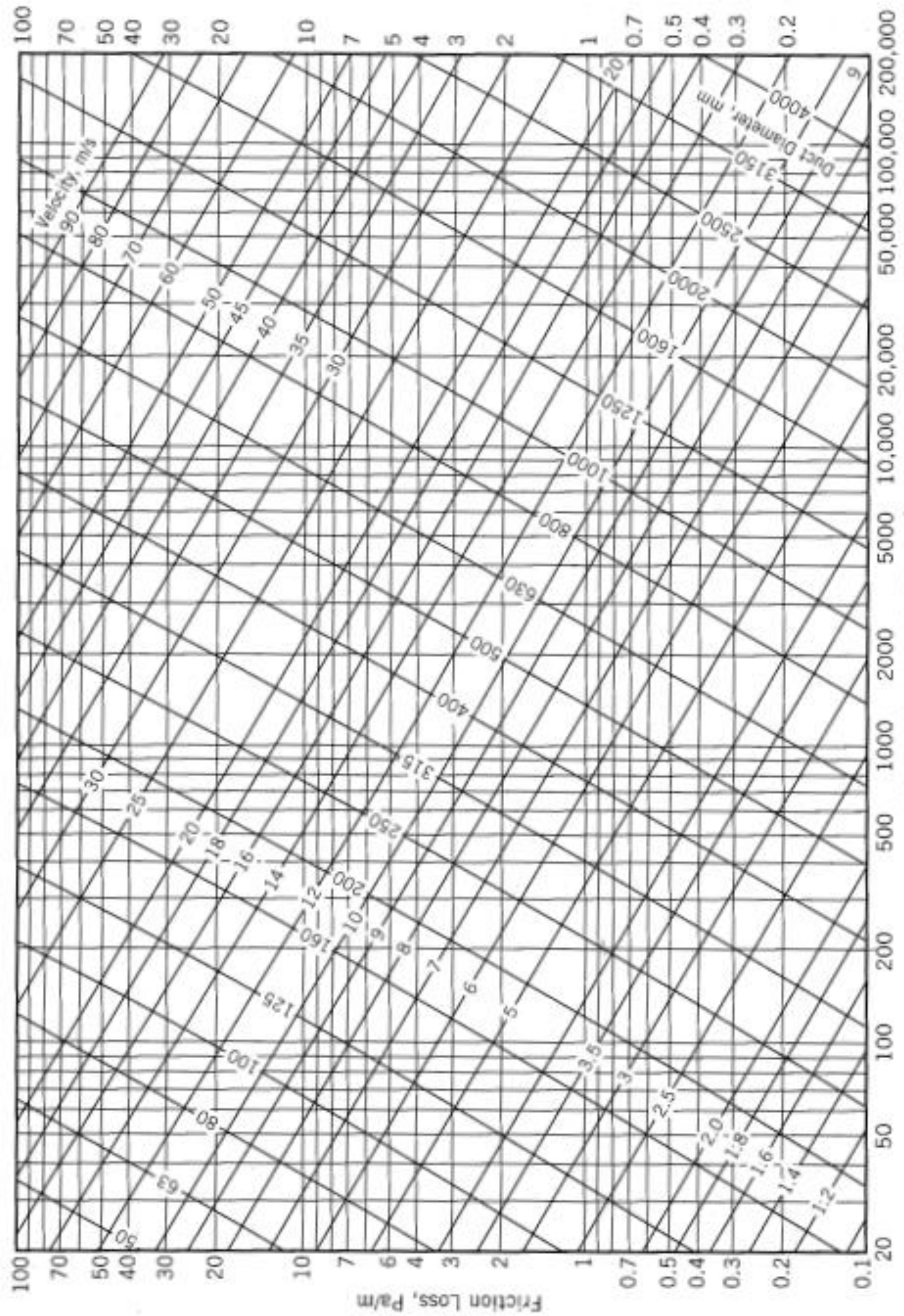

Figure 12-22 Pressure loss due to friction for galvanized steel ducts, SI units. (Reprinted by permission from *ASHRAE Handbook, Fundamentals Volume SI*, 1997.)

Source: F. C. McQuiston, J. D. Parker, J. D. Spitler, Heating, Ventilating and Air Conditioning: Analysis and Design, 6th Edition

Equations

General

$$\frac{1}{v} = \rho = \frac{p}{R_a T} \qquad P = a + bH = p_a + p_v \qquad \mu = \left[\frac{W}{W_s}\right]_{t,P}$$

$$W = \frac{m_v}{m_a} = 0.6219\frac{p_v}{p_a} \qquad \rho_v = \frac{m_w}{m_{ma}} \qquad i = i_a + W i_v$$

$$\begin{cases} kJ/kga \\ i = 1.0t + W(2501.3 + 1.86t) \\ Btu/lbma \\ i = 0.24t + W(1061.2 + 0.444t) \end{cases}$$

$$\varphi = \left[\frac{\chi_v}{\chi_s}\right]_{t,P} = \frac{W p_a}{0.6219 p_s} \qquad t_d = [T_s]_{P,W}$$

$$W_1 = \frac{c_{pa}(t_2^* - t_1) + W_{s2}^* i_{fg2}^*}{i_{v1} - i_w^*} \qquad i_{a1} + W_1 i_{v1} + (W_{s2}^* - W_1) i_w^* = W_{s2}^* i_{v2}^* + i_{a2}^*$$

Heating and cooling

$$\begin{cases} \dot{m}_a i_1 + \dot{q} = \dot{m}_a i_2 \\ i_1 = \dot{m}_a i_{a1} + W_1 i_{v1} \\ i_2 = \dot{m}_a i_{a2} + W_2 i_{v2} \end{cases} \Rightarrow \begin{cases} \dot{q} = \dot{m}_a c_p (t_2 - t_1) \\ c_p = c_{pa} + W c_{pv} \end{cases}$$

Humidification and heating

$$\dot{m}_a i_2 = \dot{q} + \dot{m}_a i_1 + \dot{m}_w i_w \qquad \frac{\Delta i}{\Delta W} = \frac{\dot{q}}{\dot{m}_a \Delta W} + i_w$$

$$\dot{m}_a W_1 + \dot{m}_w = \dot{m}_a W_2 \qquad \dot{m}_a \Delta W = \dot{m}_w$$

Dehumidification and cooling

$$\dot{m}_a i_1 = \dot{q} + \dot{m}_a i_2 + \dot{m}_w i_w \qquad \dot{q}_s = \dot{m}_a c_p (t_2 - t_1) = \dot{m}_a (i_2 - i_3)$$

$$\dot{m}_a W_1 = \dot{m}_w + \dot{m}_a W_2 \qquad \dot{q}_l = \dot{m}_a (W_2 - W_1) i_{fg} = \dot{m}_a (i_3 - i_2)$$

$$\dot{q} = \dot{m}_a (i_1 - i_2) - \dot{m}_a (W_1 - W_2) i_w \qquad SHF = \frac{\dot{q}_s}{\dot{q}}$$

Adiabatic mixing of moist air streams

$$\dot{m}_{a3} i_3 = \dot{m}_{a1} i_1 + \dot{m}_{a2} i_2 \qquad \frac{i_2 - i_3}{i_3 - i_1} = \frac{W_2 - W_3}{W_3 - W_1} = \frac{\dot{m}_{a1}}{\dot{m}_{a2}}$$

$$\begin{cases} \dot{m}_{a1} + \dot{m}_{a2} = \dot{m}_{a3} \\ \dot{m}_{a1} W_1 + \dot{m}_{a2} W_2 = \dot{m}_{a3} W_3 \end{cases} \qquad \frac{\dot{m}_{a1}}{\dot{m}_{a2}} = \frac{\overline{23}}{\overline{13}};\ \frac{\dot{m}_{a2}}{\dot{m}_{a3}} = \frac{\overline{13}}{\overline{12}};\ \frac{\dot{m}_{a1}}{\dot{m}_{a3}} = \frac{\overline{23}}{\overline{12}}$$

Heat Transfer

$$\dot{q} = -kA\frac{dt}{dx} = -kA\frac{T_2 - T_1}{x_2 - x_1}$$

$$R' = \frac{x_2 - x_1}{kA} \qquad R = R_1 + R_2 + \ldots.. + R_n \qquad C = \frac{1}{R} = \frac{k}{\Delta x} \qquad R' = \frac{\ln(\frac{r_o}{r_i})}{2\pi kL} \qquad \dot{q} = \frac{2\pi kL}{\ln(\frac{r_o}{r_i})}(t_i - t_o)$$

$$\dot{q} = hA[T - T_w] = \frac{T - T_w}{R'} \qquad R' = \frac{1}{hA} \qquad \dot{q}_{12} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{A_1\varepsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{A_2\varepsilon_2}}$$

$$\dot{q}_l = \frac{\dot{Q}\, i_{fg} \Delta W}{v_o} \qquad \dot{q}_s = \frac{\dot{Q}\, c_p \Delta t}{v_o}$$